The Effect of Composition and Evaporation during Oil Recovery by Combustion

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Introduction: One of the methods to recover oil is air injection leading to oil combustion. In this case the oxygen in the air burns the heavier components of the oil, generating a heat wave leading to vaporization of lighter components. The broad range of applicability is covered by combustion because not only the high temperatures increase the mobility of viscous oils but also the high thermal diffusion coefficient spreads the heat more evenly and suppresses heterogeneity effects.

Computational Methods: We study a 1-D two-phase flow process possessing a combustion front when a gaseous oxidizer (air) is injected into porous rock filled with oil composed of volatile and non-volatile components. The reactions are modeled as

ν_{ol}*(light hydrocarbons)+*$O_2 \rightarrow \nu_{gl}$*(gaseous products)*

ν_{oh}*(heavy hydrocarbons)+*$O_2 \rightarrow \nu_{gh}$*(gaseous products)*

The model equations are

$$\partial_t(\varphi X_h \rho_o s_o) + \partial_x(\rho_o u_{oh}) = -\nu_{oh} W_{rh}$$

$$\partial_t(\varphi X_l \rho_o s_o) + \partial_x(\rho_o u_{ol}) = -\nu_{ol} W_{rl} - W_v$$

$$\partial_t(\varphi Y_l \rho_g s_g) + \partial_x(\rho_g u_{gl}) = W_v$$

$$\partial_t(\varphi Y_k \rho_g s_g) + \partial_x(\rho_g u_{gk}) = -W_{rh} - W_{rl}$$

$$\partial_t(\varphi Y_r \rho_g s_g) + \partial_x(\rho_g u_{gr}) = \nu_{gh} W_{rh} + \nu_{gl} W_{rl}$$

$$\partial_t(C_m + \varphi c_o \rho_o s_o + \varphi c_g \rho_g s_g)\Delta T + \partial_x(c_o \rho_o u_o + c_g \rho_g u_g)\Delta T =$$

$$= \lambda \frac{\partial^2 T}{\partial x^2} + Q_{rh} W_{rh} + Q_{rl} W_{rl} - Q_v W_v$$

Where s_o, s_g are the liquid and gas saturations, X_i *(i=h,l)* are the heavy and light hydrocarbon mole fraction in oil phase, Y_i (*i=k,l,r*) are the oxygen, hydrocarbon and remaining gas mole fractions. W_{ri} (*i=h,l*), W_v , Q_{ri} (*i=h,l*) and Q_v are the reaction and evaporation rates and heats. ν_{oi}, ν_{gi} are the stoichiometric coefficients. Furthermore u_i, c_i, and ρ_i are the Darcy velocity, heat capacity and molar density for the liquid (*o*) and gas (*g*).

Results: The combustion mechanisms are different for light oils, where evaporation is dominant, (Fig 1) whereas for medium non-volatile oils combustion is dominant (Fig 2). In Figures 1 and 2, indicated are the distributions of the temperature T, liquid saturation s_o, oxygen mole fraction Y_K, gaseous hydrocarbon mole fraction Y_l, light oil saturation $S_o\psi_L$ and heavy oil saturation $S_o\psi_h$.

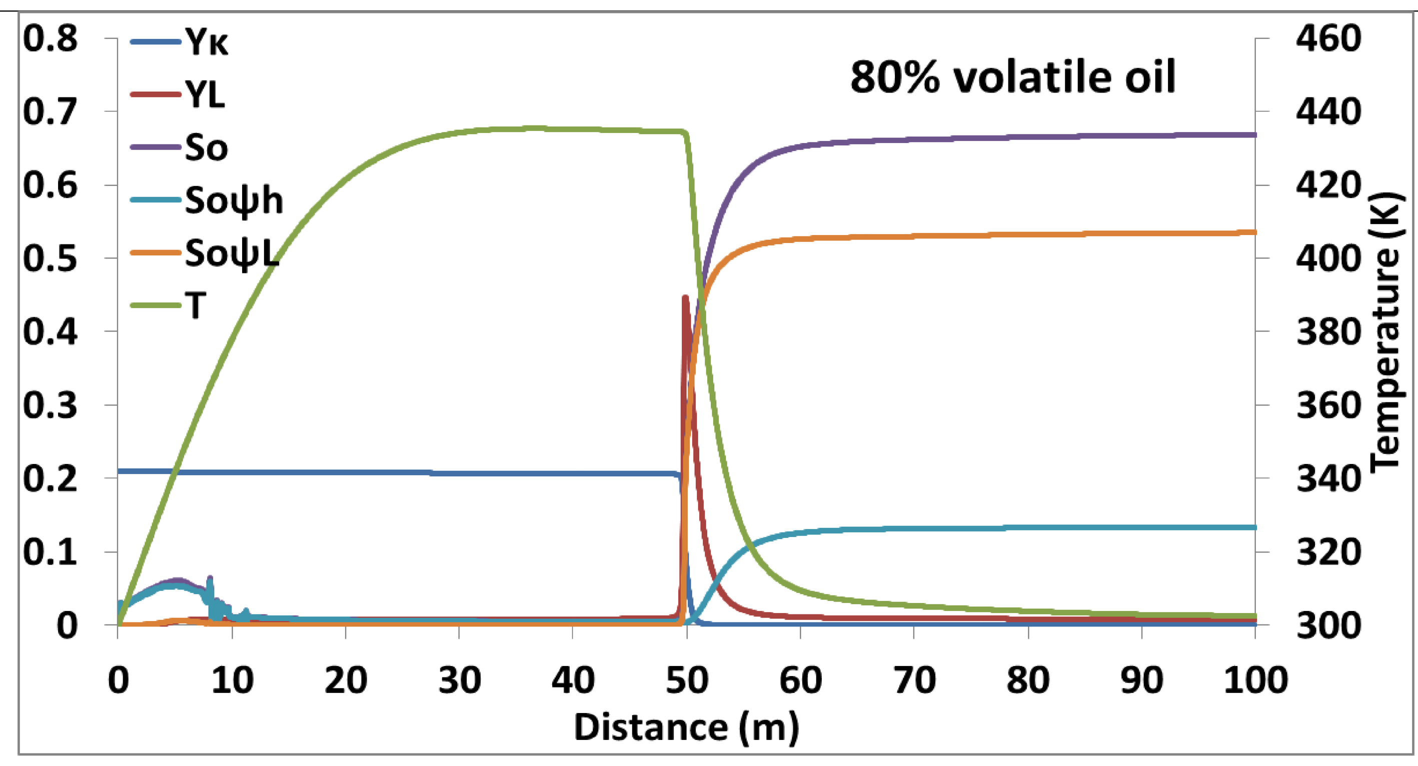

Figure 1. *Wave sequence solution with the thermal and MTO regions at t=9.7x 10^7 sec in case of ψ_h=0.2 .*

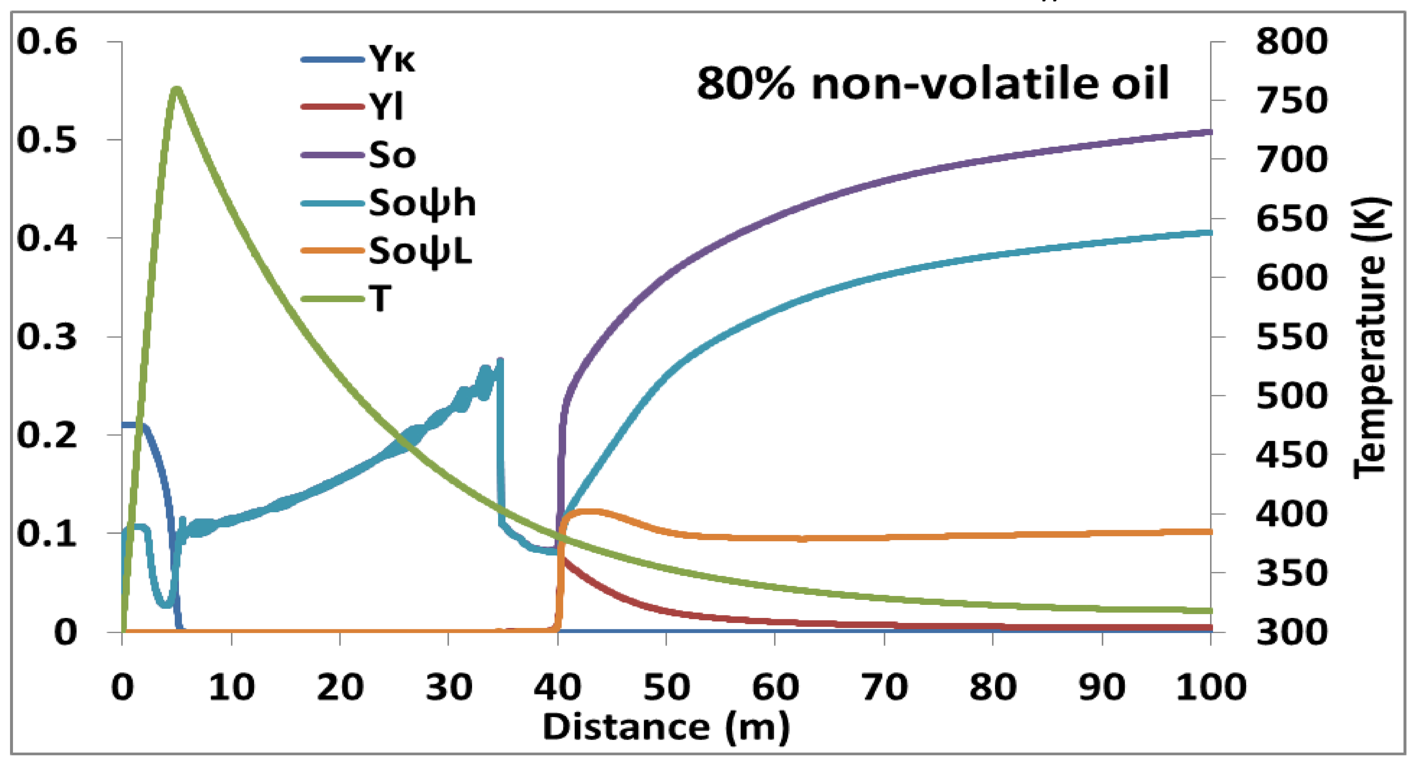

Figure 2. *Wave sequence solution with the thermal and MTO regions at t=2.1x 10^8 sec in case of ψ_h=0.8 .*

Conclusions: Generally the solution consists of three waves, i.e., a thermal wave, an MTO wave and a saturation wave[1,2] separated by constant state regions, while the sequence of evaporation and oxidation in the MTO wave changes for different sets of conditions. For a predominantly light oil mixture, evaporation occurs upstream of the combustion process. Moreover, also for the light mixture, the combustion front velocity is high as less oil remains behind in the combustion zone. For oil with more non-volatile components, the evaporation is located downstream of the combustion zone in the MTO wave. As more oil stays behind in the combustion zone, the velocity of the combustion zone is slower, whereas that the temperatures are higher. The simulations show that there is a bifurcation point, determined by the fraction of the heavy component, where the character of the combustion process changes from an evaporation dominant to a combustion dominant process.

References:

1. Mailybaev et al., Recovery of light oil by medium temperature oxidation, Transport in porous media, 97, 317-343, 2013.
2. Khoshnevis Gargar et al., Numerical Simulation of Recovery of Light Oil by Medium Temperature Oxidation in Porous Media, COMSOL conference, Italy, 2012.